DIRECT DETECTION SIGNATURES OF SELF-INTERACTING DARK MATTER WITH A LIGHT MEDIATOR

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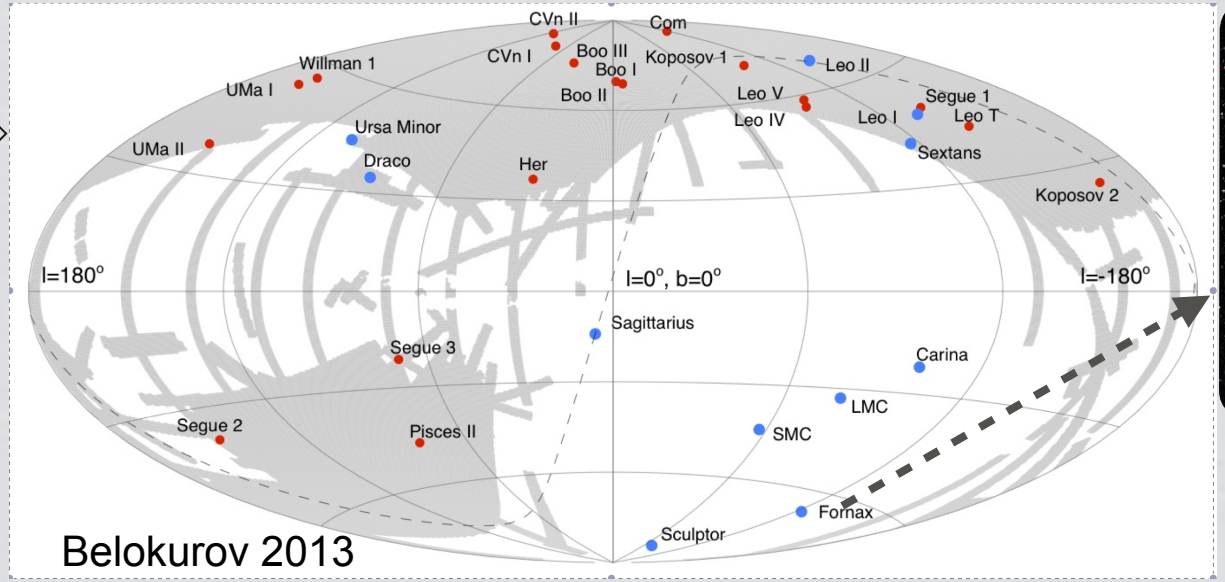
Summary

Estimates of the dark matter density in the centers of galaxies are **systematically lower** than expected. The **correlations** and **diversity** in rotation curves do not yet have an explanation.

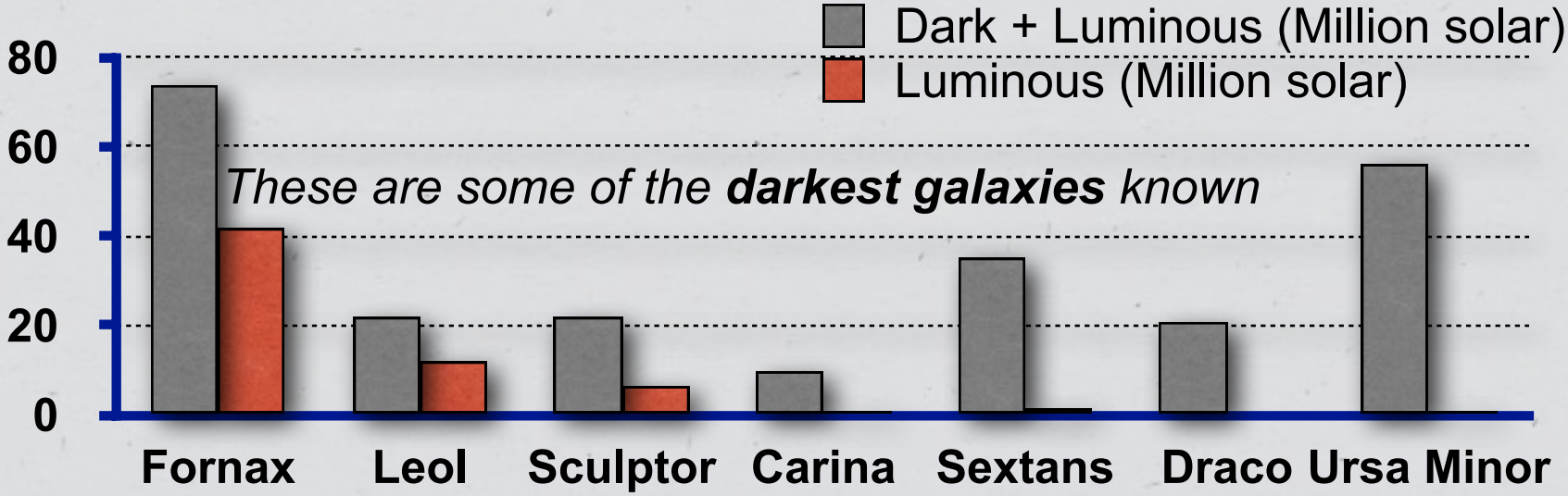
Self-interacting dark matter (SIDM) is a viable solution.

Simple SIDM models can be distinguished from WIMPs in direct detection experiments.

Dark matter in satellite galaxies

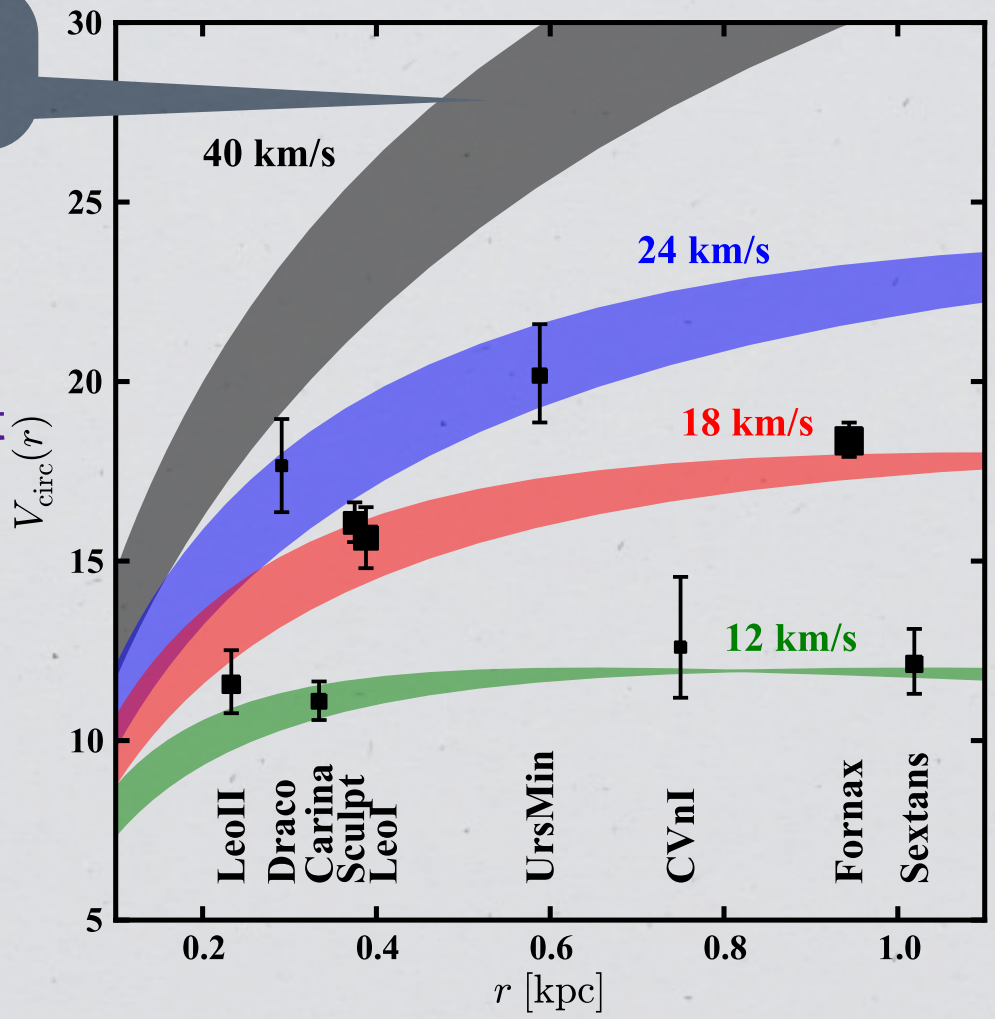


Belokurov 2013



Too big to fail? The most massive apparently don't light up...

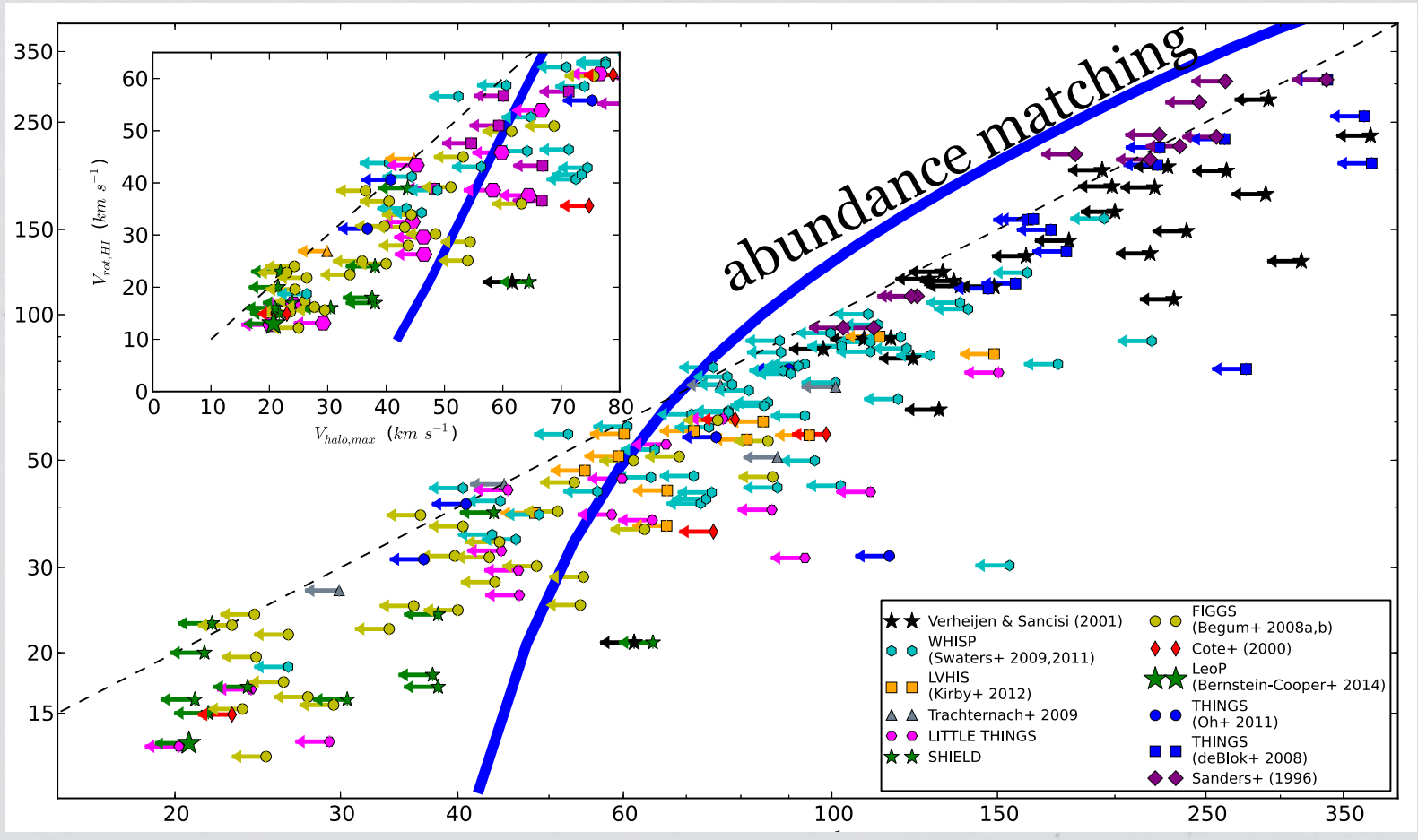
Predicted satellite galaxies not found!



Predicted satellites are denser [Boylan-Kolchin, Bullock, Kaplinghat 2011, 2012]. Also in Andromeda [Tollerud et al 2014].

Not dependent on resolving core/cusp.

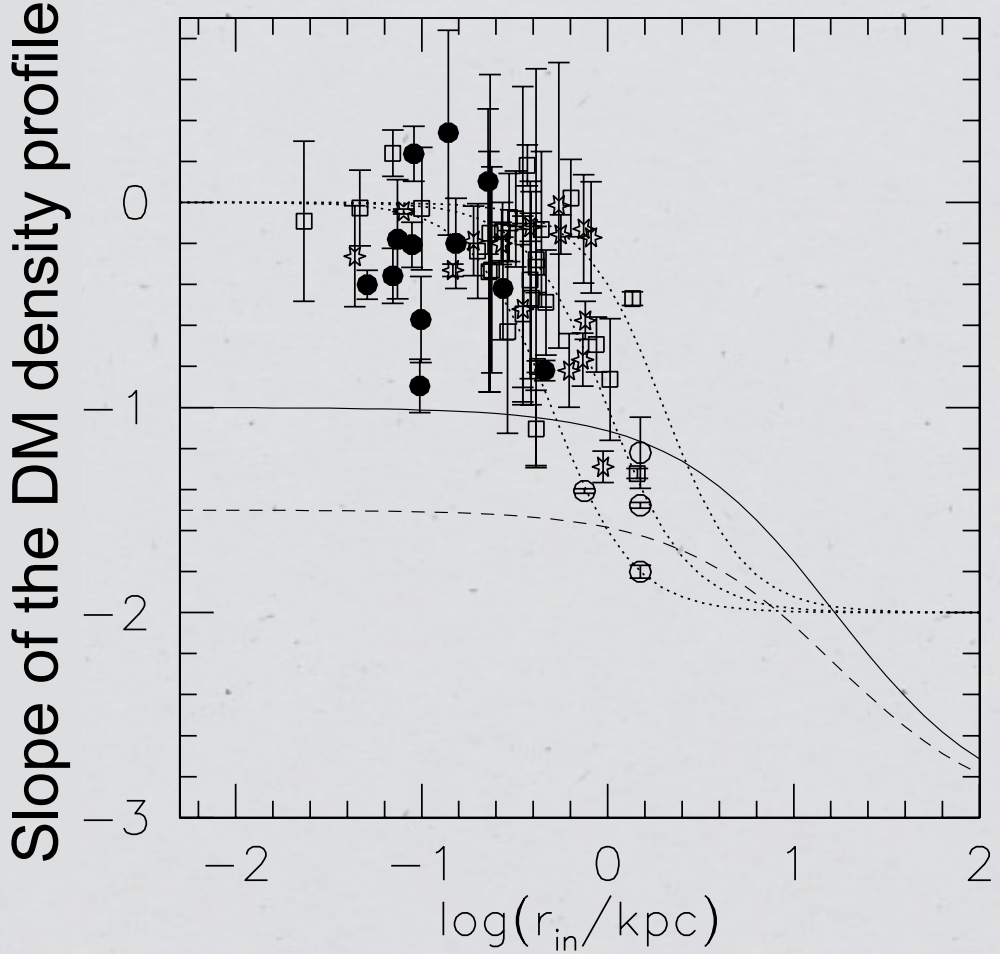
The too-big-to-fail problem in the field



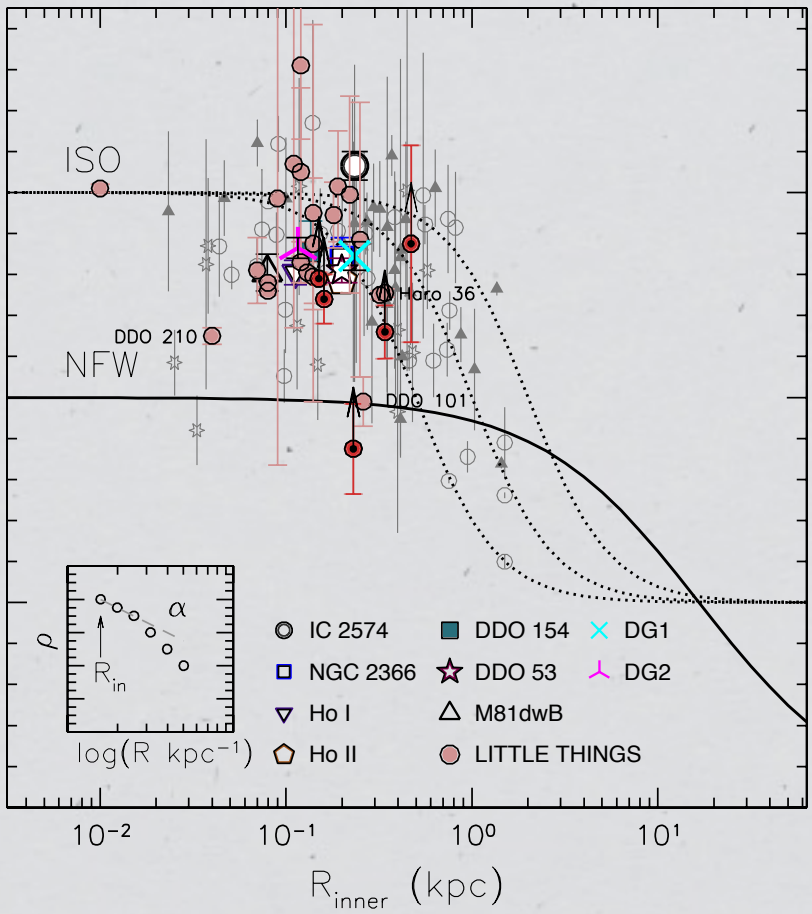
Not dependent on resolving core/cusp.

Papastergis et al 2014
Also, Klypin et al 2014
and Ferrero et al 2012

Constant density cores in nearby dwarf galaxies



deBlok and Bosma, 2002



LITTLE THINGS, Oh et al 2015

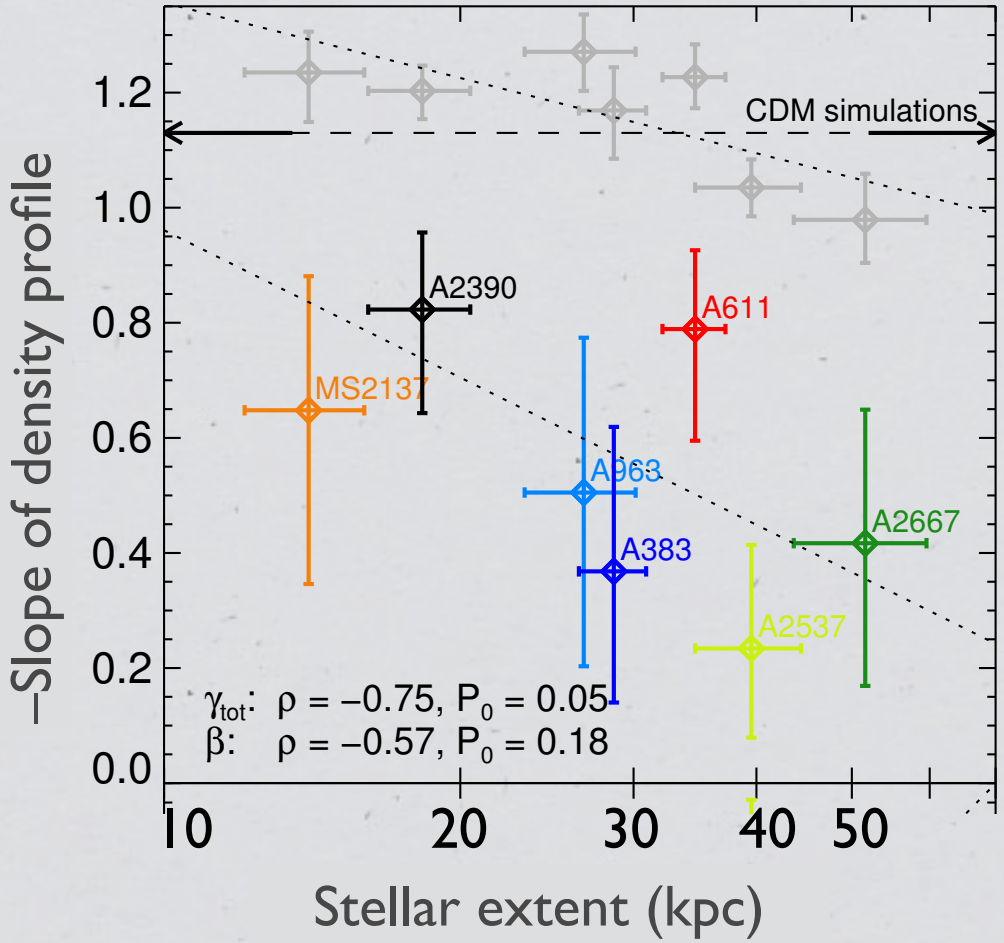
Dark matter densities in the inner regions of galaxies

Dark matter halo mass of bound objects [Mass in solar masses]	Scales of interest (distance from center)	Core (region of roughly constant density)	Lower density than predicted by CDM-only simulations
Clusters of galaxies [1e14 to 1e15]	5-50 kpc	?	Y
Elliptical galaxies [1e12 to 1e13]	1-10 kpc	?	?
Dwarf galaxies; Low surface brightness galaxies [1e10 to 1e11]	0.5-5 kpc	Y	Y TBTF
Dwarf galaxies in the local group [~1e9]	0.3-1 kpc	?	Y TBTF

Cores in clusters of galaxies

Weak lensing, strong lensing and kinematics of stars used.

Cluster masses ~ 10^{15} M_{sun}.



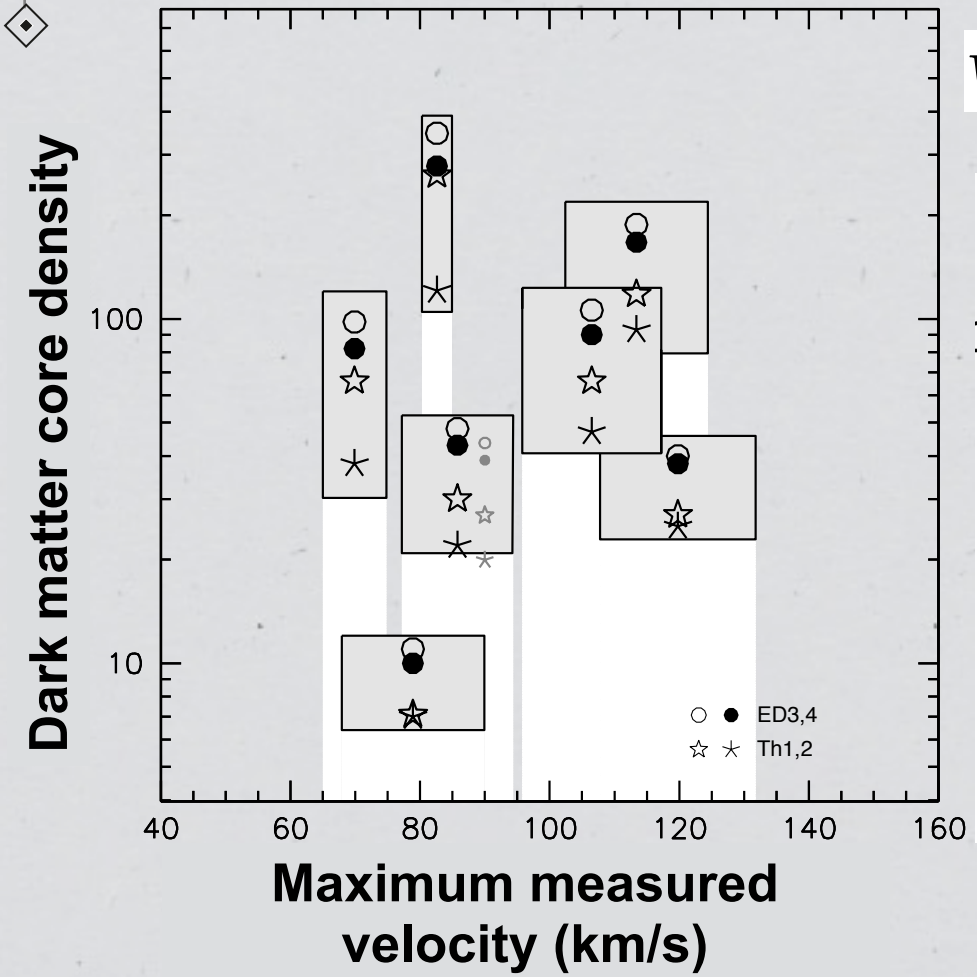
Newman et al 2012

Correlations and Diversity

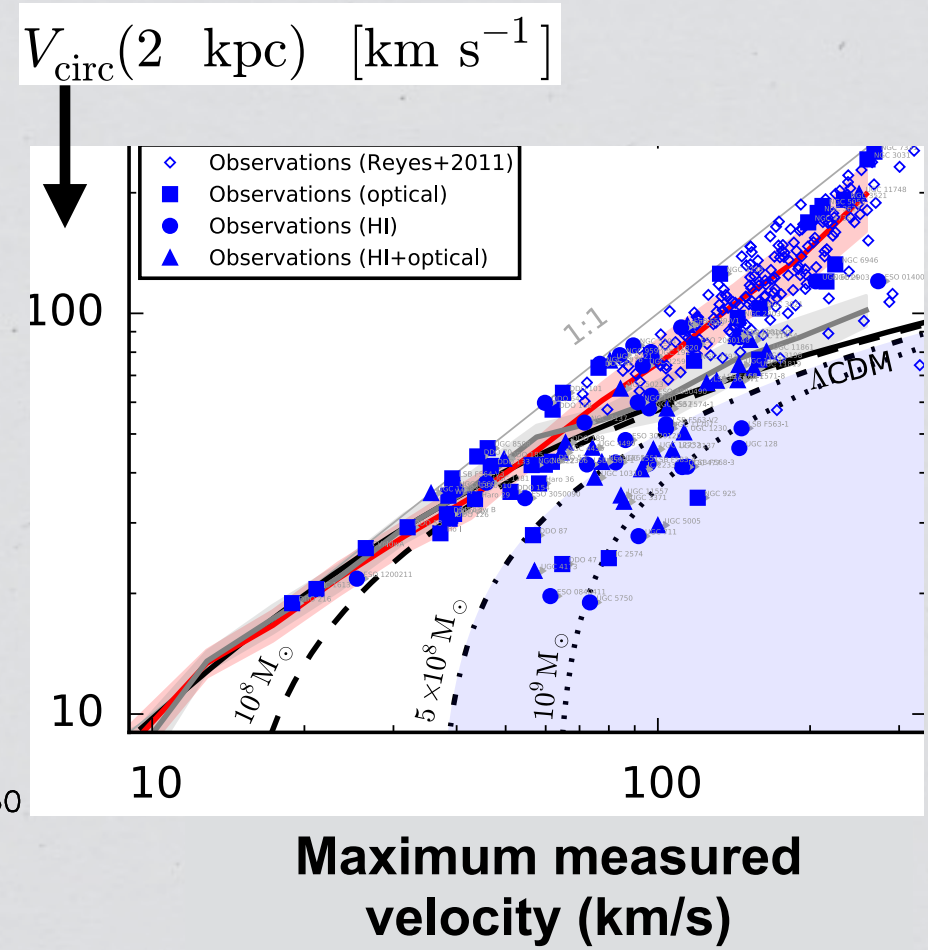
The puzzles go deeper than just the presence of cores or lowered densities. There is large **scatter** and there are **correlations** that have yet to be fully explained.

There is a large scatter in core densities

Diversity of rotation curves needs an explanation

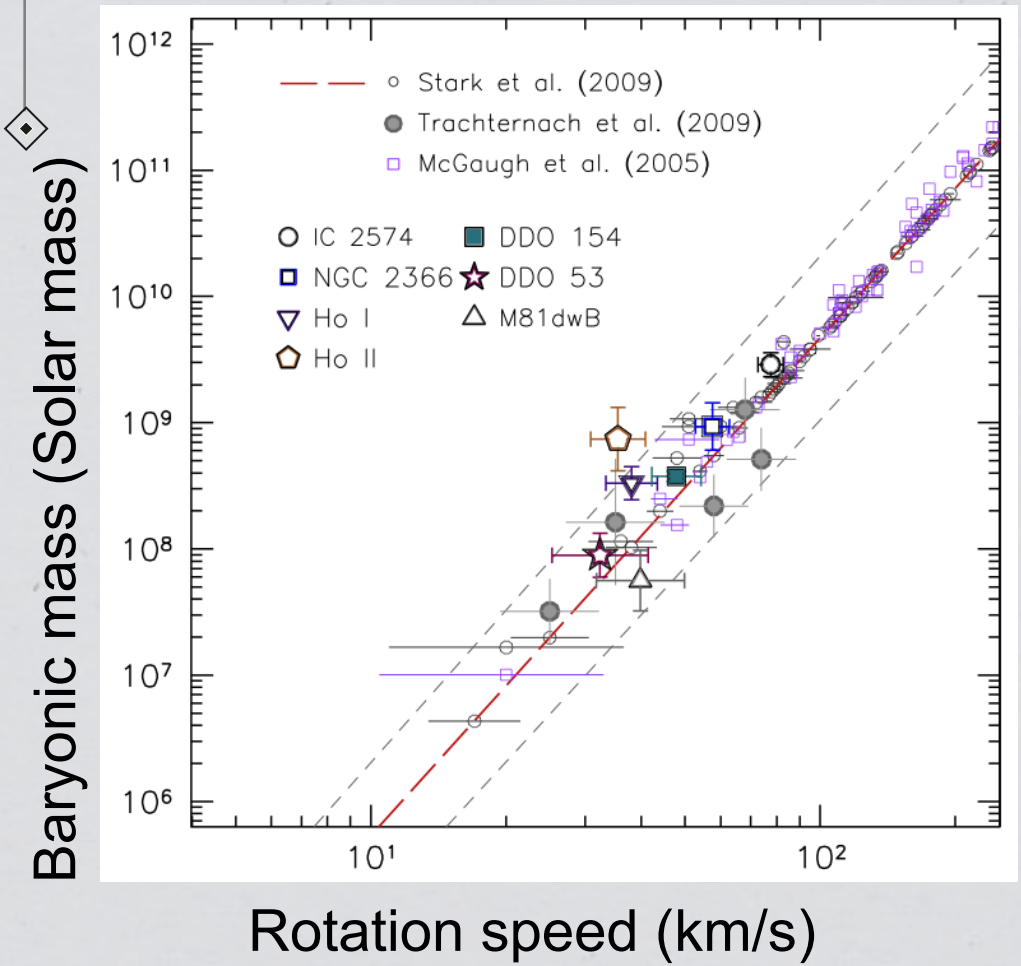


Kuzio de Naray, Martinez, Bullock, Kaplinghat, 2010

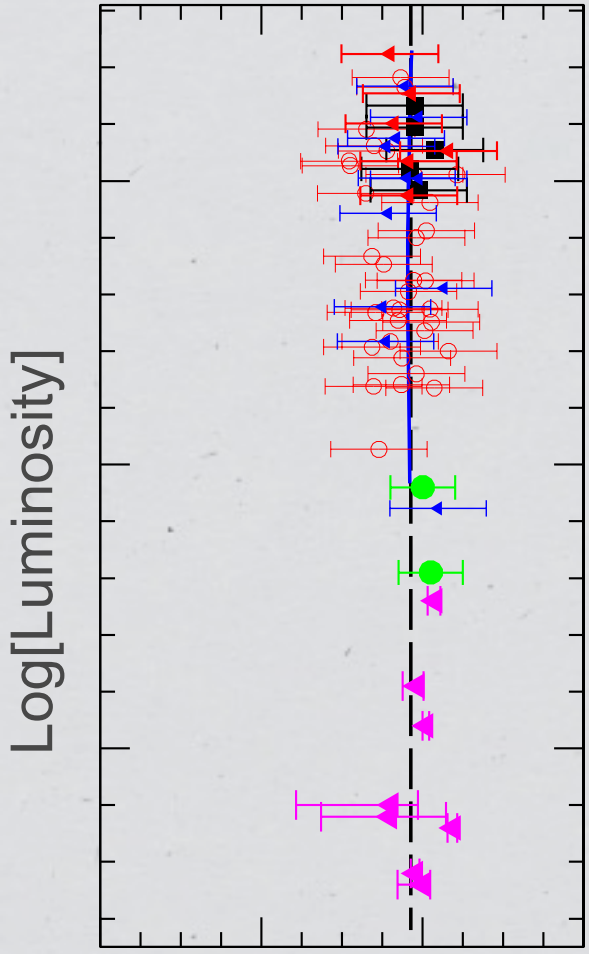


Oman et al, 2015

Correlations



Oh et al (2011)
Trachternach et al (2009)
McGaugh et al (2005)



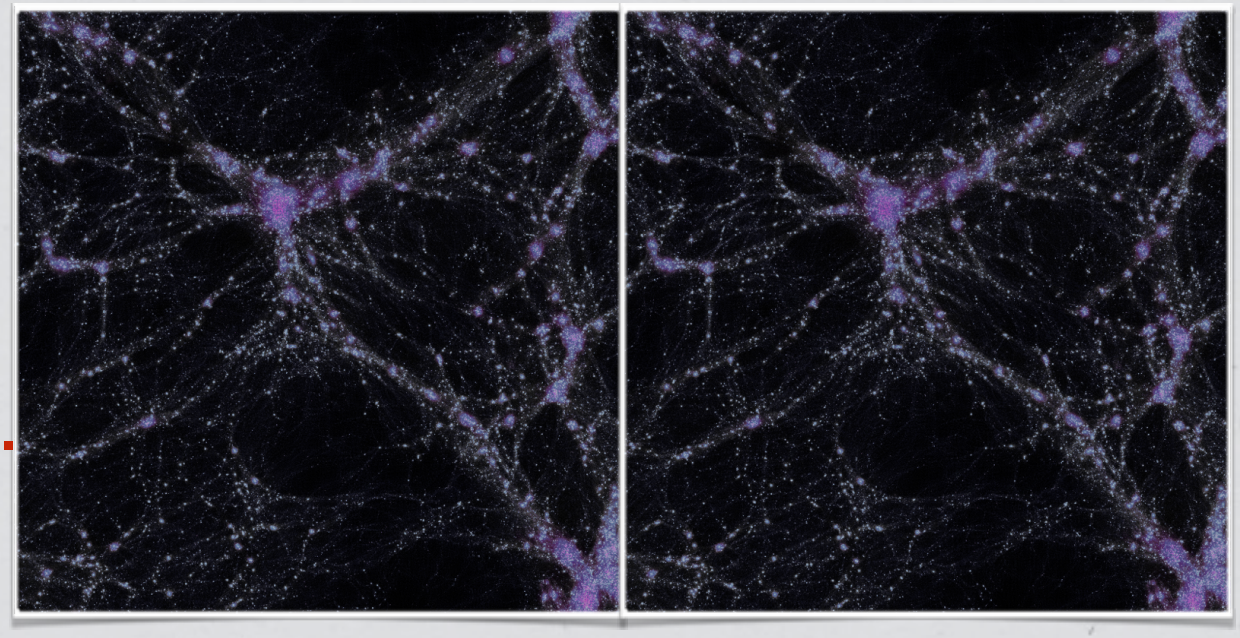
Salucci, Wilkinson, et al 2012

Possible solutions

Cold dark matter with appropriate ***feedback recipes***.

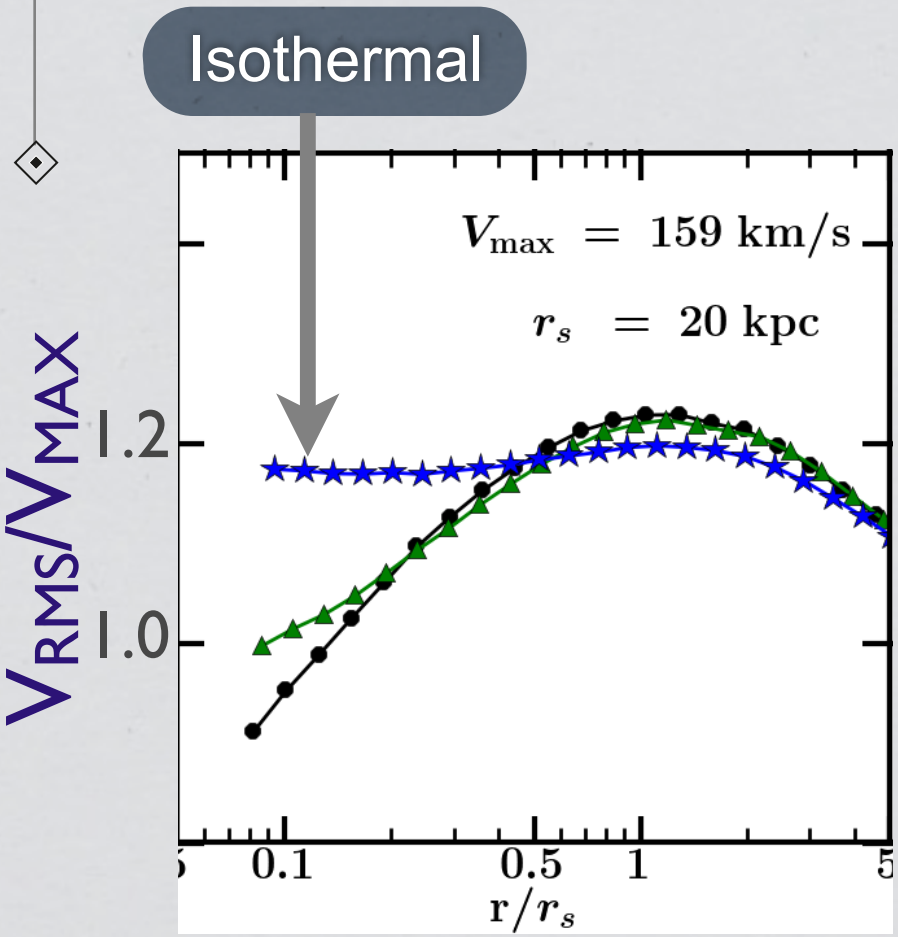
Self-interacting dark matter : what are the correlated signatures?

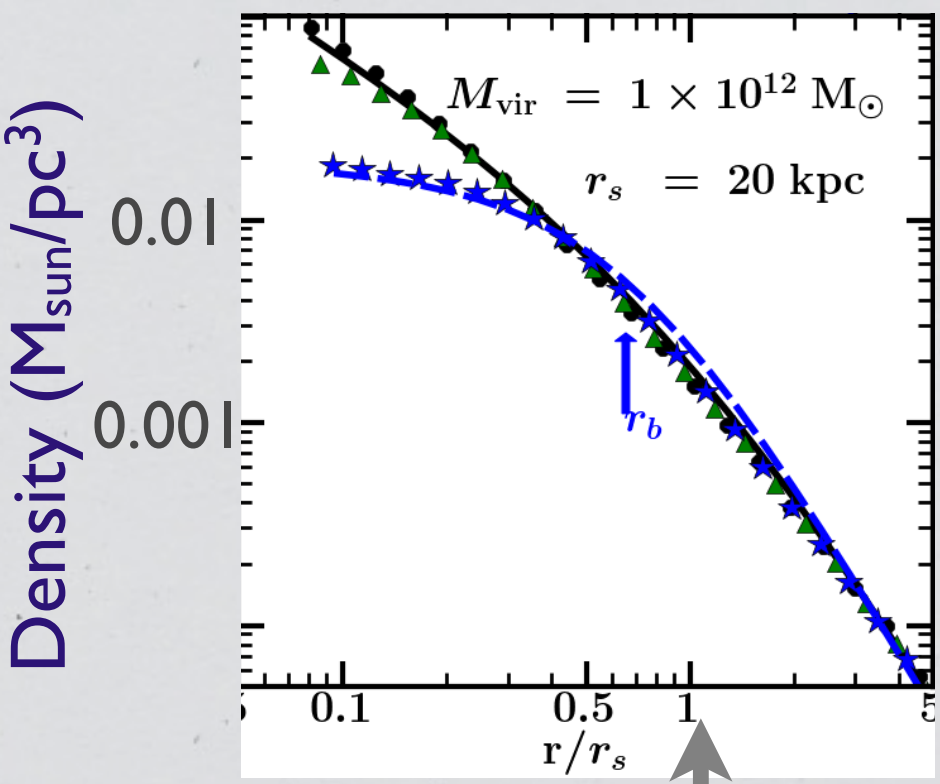
SIDM looks the same as CDM on large scales, so it passes all the cosmological tests.



How does SIDM work?

Isothermal

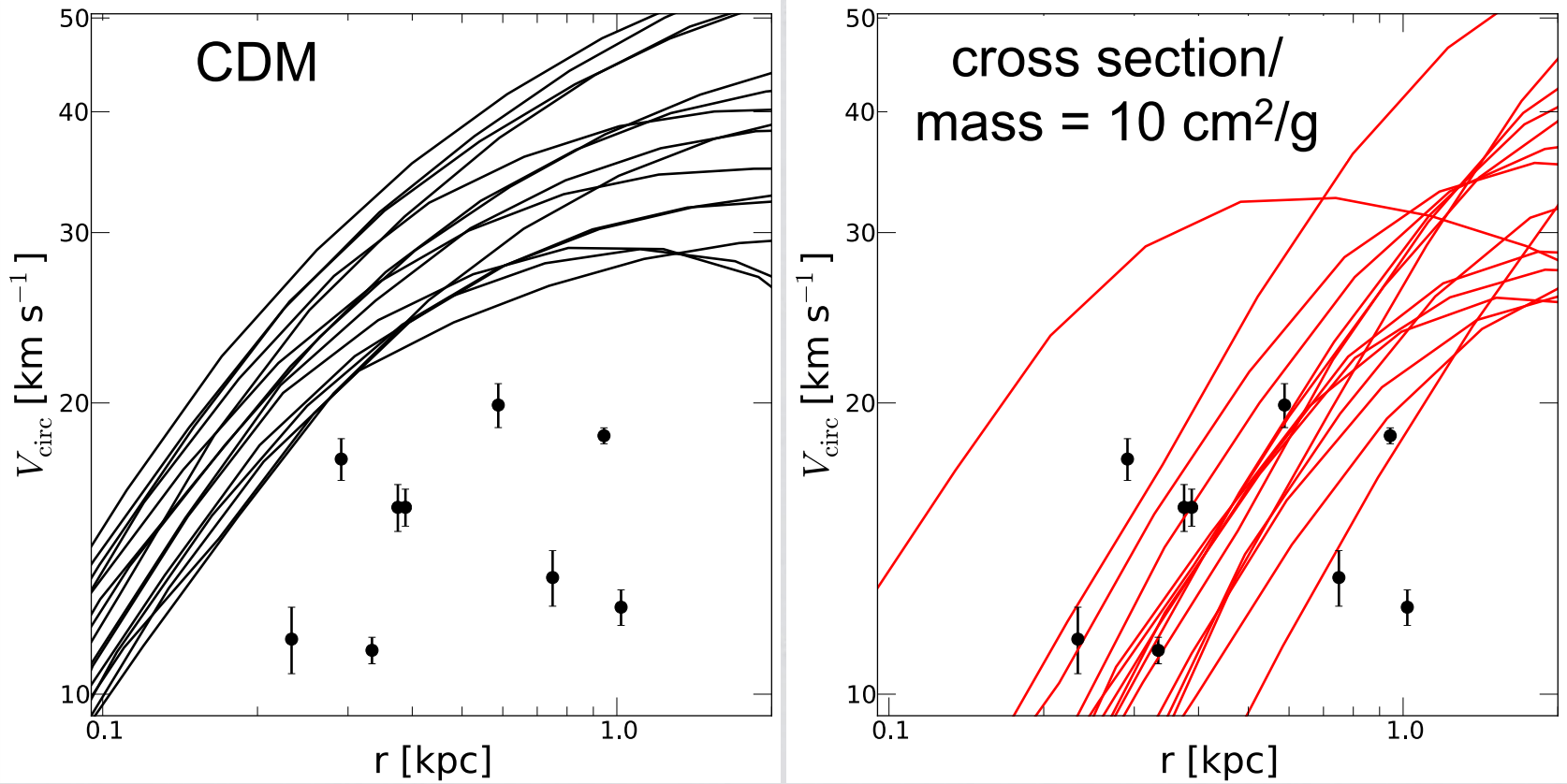




One interaction on average over halo age

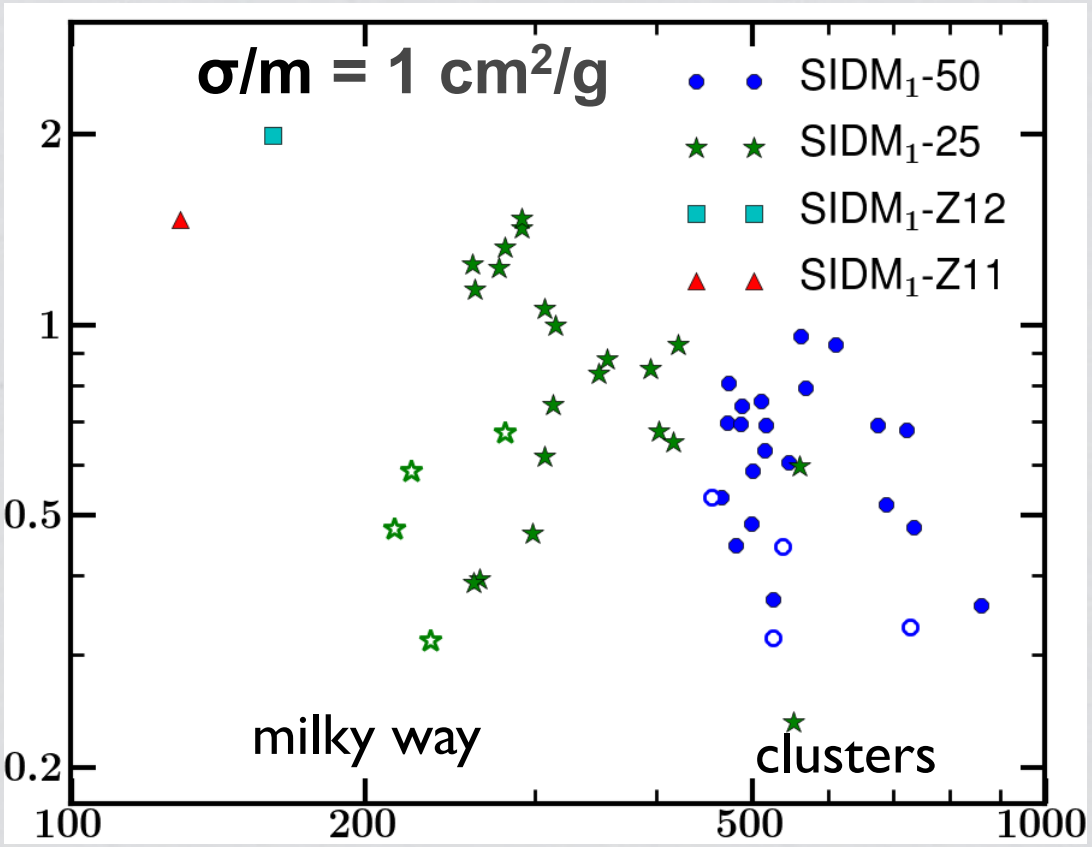
Rocha et al 2012

SIDM solution: Milky Way satellites



``Too big to fail" problem can be solved with the production of large cores [Vogelsberger, Zavala and Loeb 2012, Vogelsberger, Zavala and Walker 2012]

SIDM solution: scatter in core density



Core density is smaller for larger mass halos.

Large spread in densities at fixed halo mass.

Rocha et al (2012)

See also Fry et al (2015)

A simple SIDM model

$$\mathcal{L} = g_\chi \bar{\chi} \gamma^\mu \chi \phi_\mu + m_\chi \bar{\chi} \chi + m_\phi^2 \phi^\mu \phi_\mu$$

Symmetric: Relic density achieved through $\chi\bar{\chi} \rightarrow \phi\phi$

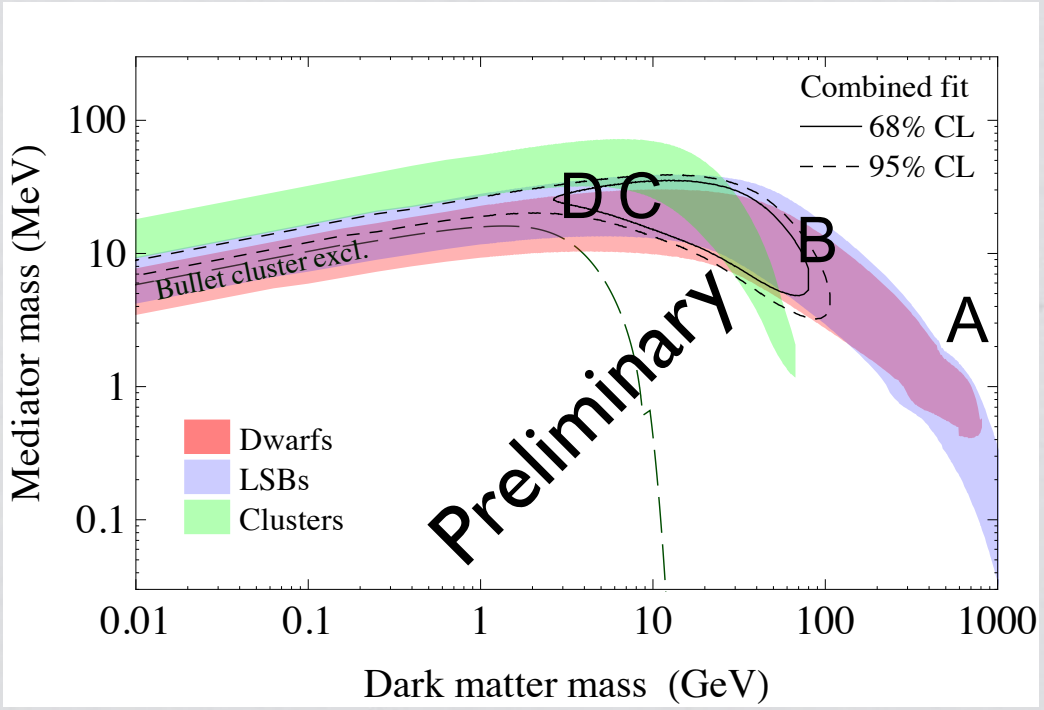
Asymmetric: cross section ($\chi\bar{\chi} \rightarrow \phi\phi$) > thermal relic cross section

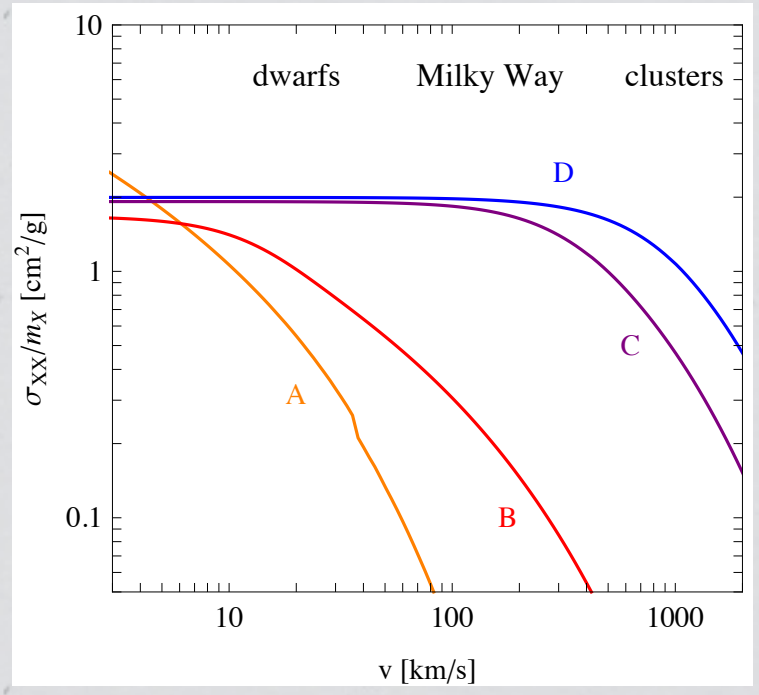
$$V = \pm \frac{\alpha_x}{r} \exp\left(-m_\phi r\right)$$

A wide range of velocity dependences possible.

Tulin, Yu, Zurek 2012

Astrophysics can fix the mediator and dark matter masses!





Kaplinghat, Tulin and Yu, in prep

A simple SIDM model

The light mediator must decay or it will over-close the universe.

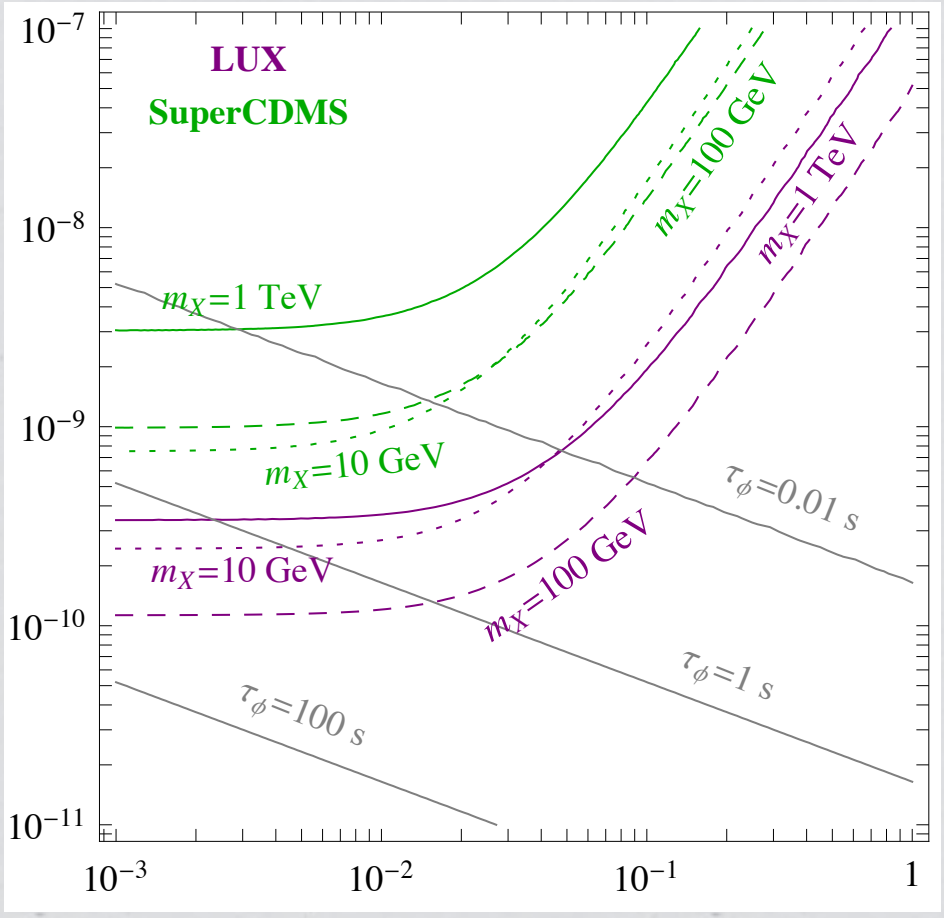
Unless there are other light particles in the hidden sector, this requires coupling to SM fields. **Direct and indirect searches.**

Direct: Contact interaction not always a good approximation.

$$\frac{\mathrm{d}\sigma_{XT}}{\mathrm{d}q^2} = \frac{4\pi\alpha_{\mathrm{em}}\alpha_X\epsilon_\gamma^2 Z^2}{(q^2+m_\phi^2)^2}\frac{1}{v^2}F_T^2(q^2)$$

Kaplinghat, Tulin, Yu, PRD (2013)
Fornengo, Panci and Regis (2011)

Simple model already constrained



Region above colored lines ruled out.

Magenta: LUX
Green: SuperCDMS

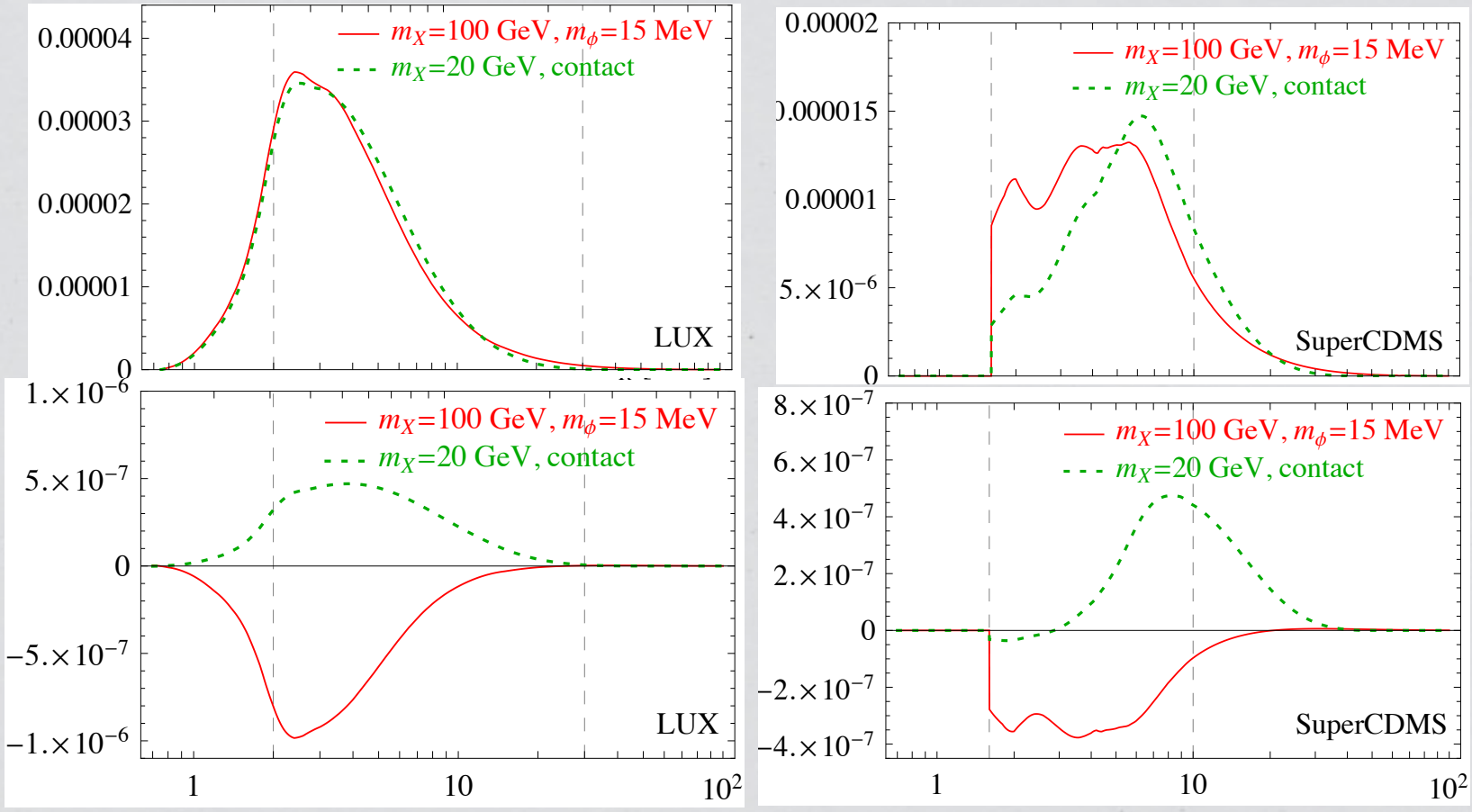
Dotted: DM mass = 10 GeV
Dashed: DM mass = 100 GeV
Solid: DM mass = 1 TeV

Del Nobile, Kaplinghat and Yu, in prep

Distinguishing WIMP from SIDM in direct detection experiments

Del Nobile, Kaplinghat and Yu, in prep

Multiple targets and annual modulation are crucial



del Nobile, Kaplinghat and Yu, in prep

Non-abelian hidden sector models

Rich SIDM phenomenology in non-abelian hidden sectors with supersymmetry [Boddy, Feng, Kaplinghat and Tait (2014)] **or without** [Cline, Liu, Moore, Xue (2014), Hochberg, Kuflik, Murayama, Volansky, Wacker (2014)]

New possibilities include a sub-dominant *ultra-strongly interacting* component (glueball), which could seed supermassive black holes! [Boddy, Feng, Kaplinghat and Tait (2014), Pollack, Spergel, Steinhardt (2015)]

Excited states could have astrophysical implications (such as X-ray lines) [Boddy, Feng, Kaplinghat, Shadmi, Tait (2015)]

Relic density could be set by 3->2 process freeze out [Hochberg, Kuflik, Volansky, Wacker (2014)]

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